FROM PRESENT SURVEYING TO FUTURE PROSPECTING OF THE ASTEROID BELT

P.E. Clark, M.L. Rilee, L3 Communications GSI
S.A. Curtis, G. Marr, C.Y. Cheung, W. Truszkowski, NASA/GSFC

What are ANTS and PAM?

ANTS: Autonomous NanoTechnology Swarm

- Inspired by success of social insect colonies where
  - Within their specialties, individuals outperform generalists
  - With sufficiently efficient social interaction and coordination, groups of specialists outperform groups of generalists.
- A Generic Mission Architecture based on:
  - Spatially distributed spacecraft
  - Autonomous, redundant components with high plasticity
  - Hierarchical (multilevel, dense heterarchy) organization

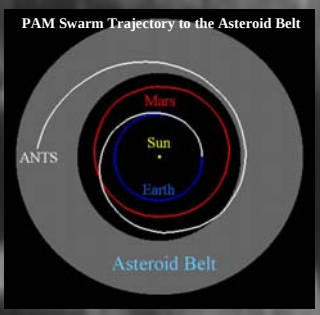
PAM: Prospecting Asteroid Mission

- An ANTS application for survey of large populations
  - 1000 spacecraft swarm
  - 10 types of 'specialists' with common spacecraft bus
  - 10 subswarms, ~100 spacecraft each, ~10 each specialist
  - Solar sail propulsion system requiring no expendables
  - Small nuclear batteries meet 100's of milliwatt power requirements
  - Designs applicable to low G environments <3.5 AU
  - Primary objective is the exploration of the asteroid belt in search of resources and material with astrobiologically relevant origins and signatures

PAM Estimated Mission Parameters and Requirements

• Mission Date	2025
• Mission Duration	5-10 years (TBR)
• Mission Location	1.0 - 3.5 AU
• Spacecraft Mass	1 kg
• Power System Mass	0.25 kg
• Power Required	100-300 milliwatts
• Storage Life in Space	5-10 years
• Deployment Temperature	-40 deg C (TBR)
• Spacecraft Attitude	3-axis stable

- Operations:
  - Deep space operations far from Earth & Sun
  - 1 month of optimal science operations at each asteroid
  - Full suite of science instruments deployed at each asteroid
  - Concurrent operations at tens of asteroids
  - No single point failure; robust to minor faults/catastrophic failures
  - Optimal operations in spite of mission attrition



PAM Concept Development Methodology

- Develop Conceptual Model for Behavior
  - Neural Basis Function based on bilevel intelligence
  - Combines capability for autonomous and collective behavior
  - Model applies at all levels: component, subsystem, spacecraft, subswarm
  - Individual operational components connect to each other through specially designed interface
- Develop scaled physical models and simulations to illustrate modularity, configurability, scalability
  - Solar Sail Structure and deployment
  - Subsystem platform
  - Predeployed, packaged spacecraft
  - Predeployment manufacturing
- Formulate requirements and operational scenarios driven by variable size, irregular mass distribution, and highly variable composition in low G environment.

PAM Concept Development: Autonomous Assembly

- Autonomous assembly and deployment minimizes resource requirements, including bandwidth and human labor.
- Components are composed of carbon nanotubule strands (tethers) or fibers (surfaces) reversibly deployable and stowable from NEMS nodes, allowing for orders of magnitude decrease in packaging or stowing volume.
  - A tetrahedron of NEMS nodes forms basic building block.
  - Assembly is based on creating 2D layers of interconnected NEMS nodes in two patterns.
  - Specialized subsystem nodes can be added to any layer.
  - 2 layers of different pattern form the sail support.
  - A 3 layer sandwich, with different pattern layer in the middle, forms the subsystem platform.
  - Subsystems are tethered together.
  - After assembly, spacecraft are stowed, spooled back into nodes.
  - 1000 autonomous 10 centimeter, 1 kg boxes would stow into a 1 meter, 1000 kg cube.

PAM Concept Development: Current Issues

- Selection of 10 instrument specialties and exploration priorities, as shown in the Science Measurement Table, allow an asteroid survey which can't be obtained from earth-based observations or single spacecraft missions.
  - Incremental improvements in optics and computer technologies will continue to allow the spectroscopic analysis and dynamic modeling of a growing number of asteroids from earth-based observations.
  - The increased numbers of objects studied will still tend to be those most readily observable-the larger, brighter, closer objects.
  - Models based on these observations will thus not truly represent a cross-section of the asteroid population.
  - Current asteroid mission strategies involve only small numbers of spacecraft and targets.
  - Understanding the modification of the surface through dynamic interactions, or space weathering, as well as understanding the relationship between meteorite samples and the small body populations demands high resolution data which can only be obtained by visiting asteroids.

Science Objectives for Asteroid Exploration

Asteroids III Questions	PAM Addressing Strategy
How has the compositional gradient evolved from protoplanetary accretion to the present? How have dynamic interactions affected the physical surface and compositional structures? What is the relationship between these surface modifications and underlying structures?	Spectrometer compositional measurements from 100's of targets with wide range of ages, including the darker, farther, smaller ones unlikely to be observed from Earth. Imaging/Ranging/Radio Science static and dynamic figure parameters, physical and interior structure with details unobservable from Earth for 100's of targets. Correlation of elemental abundance, mineralogy, and physical properties of regolith from combined spectrometer data.
What was the original distribution of parent bodies and how are dynamically or geochemically linked bodies associated with the original population?	Detailed correlation of composition from spectrometer measurements, physical and dynamic properties from imagers, ranging and radio devices not available from Earth.
Where are the surviving protoplanet remnants? What do these fragments, and asteroid cratering records say about planet formation and evolution when combined with meteorite samples?	Observations of small objects unobservable from the Earth by all instruments. Detailed imaging of impact features to meter or tens of meters resolution. Comprehensive compositional profiles for 100's of targets from combined spectrometer data.

Architectural Self Similarity, Autonomy at all levels
3D HIERARCHICAL NEURAL SYSTEM
FOR A 4 SUBSYSTEM WORKER